

**Process for the preparation of beads comprising a
crosslinked inorganic matrix**

The present invention relates to a process for the
5 preparation of beads comprising a solid crosslinked
inorganic matrix and to the beads obtained.

Materials composed of silica particles are used in many
fields, for example in the medical field or in the
10 cosmetics industry. When the particles have sizes of
the order of a micron, they constitute pulverulent
materials which are difficult to handle. Particles of
the order of a millimeter do not exhibit these
disadvantages and various processes for their
15 manufacture have been developed.

One of these processes consists in preparing a
suspension comprising a preprepared oxide powder and an
organic binder, in forming (for example by extrusion),
20 in then consolidating by a heat treatment and in
optionally depositing an active phase in the pores.
Such a process involves specific equipment in order to
provide for the forming and the geometry of the
particles thus formed. Another process consists in
25 preparing an aqueous suspension comprising an oxide
powder and a binder and in then adding this suspension
to an oil in order to produce a microemulsion of
aqueous droplets which comprise an inorganic phase
which crosslinks. However, by this process, only beads
30 with a size of the order of a micron, of between 0.1
and 100 microns, can be obtained.

US-4 063 856 discloses a process for the production of
beads of an inorganic material which consists in
35 dissolving in water an organic binder, for example an
alginate, capable of gelling in the presence of a
divalent or trivalent cation salt (for example a
calcium salt), in suspending in said solution the
precursors of the inorganic material forming the beads

and in then introducing this suspension dropwise into a solution of said divalent or trivalent salt. In addition, US-4 797 358 discloses a process for the preparation of silica grains comprising a microorganism or an enzyme. The process consists in preparing an aqueous mixture comprising the microorganism or the enzyme, an alginate and a silica salt and in then adding this mixture to an aqueous solution of a polyvalent cation salt (calcium chloride, aluminum chloride, calcium acetate, aluminum sulfate) in order to obtain gelled grains. The beads thus obtained are soft beads. In the process of these two documents, the silica added constitutes a simple inorganic filler dispersed within the gelled alginate matrix and does not in any way form a crosslinked solid matrix.

The aim of the present invention is to provide a process for the preparation of beads having a crosslinked inorganic matrix with a size controlled in the millimeter range, and also the beads obtained.

The process according to the present invention for the production of beads comprising a crosslinked inorganic matrix is characterized in that it consists:

- in preparing gelled beads by pouring a suspension comprising a precursor of the inorganic matrix and an alginate dropwise into a solution of a polyvalent cation salt, the pH of which is less than 3, preferably less than 2,
- and in crosslinking the precursor of the inorganic matrix by a sol-gel process.

The term "crosslinked inorganic matrix" is understood to mean a matrix in which the constituent components (molecules or particles) are connected by a three-dimensional network. The term "polyvalent cation" is understood to mean a cation having a charge at least equal to 2.

The alginate used to form soft beads can be an alkali metal alginate. Sodium alginate is particularly preferred. The combined actions of the polyvalent cation (which exchanges with the alkali metal ions of the alginate) and of the acidity of the medium contribute to gelling this alginate and to congealing the drops as "soft" beads. The time for maintaining beads in this solution can vary between 1 hour and 24 hours.

The precursor of the inorganic matrix is an inorganic compound capable of crosslinking by a sol-gel process chosen from inorganic compounds which have hydroxyl groups bonded to a metal M when they are in solution. M can be Si, Al, Ti or Zr. Si and Al are particularly preferred. These compounds can be chosen from compounds capable of gelling according to the polymerization of molecular entities (PME) mechanism and from compounds capable of gelling according to the destabilization of colloidal solutions (DCS) mechanism. These mechanisms are described in particular by C.J. Brinker & G.W. Scherrer ["Sol-Gel Science, The Physics and Chemistry of Sol-Gel Processing", Eds, 1990, Academic Press Inc., Harcourt Brace Jovanovich Publishers, ISBN 0-12-134970-5], or by M. Henry, J.P. Jolivet & J. Livage ["De la solution à l'oxyde" [From the solution to the oxide], InterEditions/CNRS Editions Eds, 1995 Paris, ISBN 2-271-05252-1].

Mention may be made, among compounds of the PME type, of alkali metal silicates (in particular sodium silicate). Mention may be made, among compounds of the DCS type, of alumina of boehmite type and of colloidal silica.

A compound of the PME type based on silica can be crosslinked by a fluoride, in particular an alkali metal fluoride. An aqueous sodium fluoride solution,

the fluoride content of which is between 0.001M and 1M, is particularly appropriate. In this case, the gelling of the alginate and the crosslinking of the inorganic matrix are carried out in two successive stages. It is
5 desirable to leave the reaction medium, comprising the beads formed by the gelled alginate, standing at ambient temperature for a time of between 1 and 24 hours, before subjecting them to the action of the fluoride. During the stage of crosslinking the
10 inorganic precursor, the beads are kept suspended in the reaction medium comprising the fluoride with gentle stirring, until the silica has completely crosslinked. A time of between 6 and 72 hours is generally appropriate.

15 For a compound of the DCS type, the pH of less than 3 of the reaction medium during the gelling of the alginate is sufficient to bring about crosslinking. The gelling of the alginate and the crosslinking of the
20 inorganic matrix are consequently carried out simultaneously. A pH of less than 2 is particularly preferred. It is desirable to leave the reaction medium, comprising the beads formed by the gelled alginate and the crosslinked inorganic matrix, standing
25 at ambient temperature for a time of between 1 and 24 hours.

The process is carried out at a temperature between 10°C and 60°C. It is particularly advantageous to
30 operate at ambient temperature.

The polyvalent cation salt used for the gelling of the alginate can be chosen from salts for which the anion is a halide, a nitrate or a sulfate and for which the
35 cation is an alkaline-earth metal, transition metal or noble metal cation. Mention may be made, by way of examples, of nickel, iron, cobalt, aluminum, calcium, tin, zinc or platinum salts. When a precursor of the PME type (for example a silicate) is used as precursor

of the inorganic matrix, the cation of the salt used as gelling agent for the alginate must be other than calcium. This is because, during the crosslinking of the silicate by the fluoride, the calcium would be
5 extracted from the alginate gel by the fluoride ions to form CaF_2 , which is insoluble in an aqueous medium, and the gel structure of the alginate would be destroyed.

The material obtained after crosslinking the inorganic
10 matrix is formed of beads suspended in an aqueous medium. The beads formed have a diameter of 0.5 mm to a few mm, generally of 0.5 mm to 6 mm. They are composed of a hydrated matrix of gelled alginate, of a crosslinked inorganic matrix resulting from the gelling
15 of the inorganic precursor by a sol-gel process, and of a hydroxide of the polyvalent cation of the salt used as gelling agent. At this stage, the product can be stored as is for several days. The diameter of the beads depends in particular on the size of the drops of
20 solution poured into the polyvalent cation salt solution. This diameter can be adjusted by choosing the appropriate equipment for the formation of the drops.

The composition and the properties of the beads can be
25 modified by the choice of the polyvalent salt used as gelling agent for the alginate. For example, the use of an iron salt as gelling agent for the alginate gives a red-brown coloring to the beads, whereas the use of an aluminum salt does not give a coloring. Modifications
30 can also be obtained by addition of various compounds to the reaction medium before the gelling of the alginate, said compounds being chosen from those which do not have an effect on the gelling of the alginate. When the beads are intended to be used in cosmetic
35 compositions, pigments or organic dyes for cosmetic use, kaolin powder or another clay in powder form, or a coloring agent can be added to the reaction medium, before the gelling of the alginate. When it is desired to obtain porous beads, a pore-forming agent, for

example a surface-active agent, can be added to the reaction medium before the gelling of the alginate.

5 The beads obtained after crosslinking the inorganic matrix can subsequently be used as is. They can also be extracted from the liquid medium by filtration and be subjected to various other treatments. Generally, the beads are washed with water or with a basic aqueous solution at a pH < 8 in order to remove the residual
10 acidity, this washing not destroying their structure if the pH remains below 8.

In a specific embodiment, the beads separated by filtration are subjected to drying in the air,
15 optionally after having been washed with acetone or with alcohol. Dry beads formed of a material composed of an alginate network, an inorganic matrix and a hydroxide of the cation originating from the agent for gelling the alginate are thus obtained. However, such a
20 treatment results in a decrease in the size of the beads in a ratio of approximately 5/1.

In another embodiment, the process comprises a stage during which the beads separated from the reaction
25 medium by filtration are dried by lyophilization. The material constituting the beads exhibits, in this case, a composition analogous to that which is obtained by drying in the air. However, drying by lyophilization results in a markedly smaller decrease in the size of
30 the beads.

In a third embodiment, the beads extracted from the reaction medium by filtration are washed with acetone or with alcohol and are then placed in a solution
35 comprising an alkoxide of a metal M' diluted in an anhydrous organic solvent compatible with the alkoxide. The metal M' can be any metal which can give an alkoxide of the form $M'(OR)_n$, R being an alkyl group and n being the valency of M'. Mention may be made, by

way of examples, of titanium, zirconium, aluminum, niobium and tantalum. The organic solvent is preferably the alcohol which corresponds to the alkoxy group of the metal alkoxide (for example, butanol for titanium
5 tert-butoxide, propanol for titanium isopropoxide). The alkoxide hydrolyzes only on contact with the bead as the latter comprises residual water. Beads formed of a core having a composition analogous to that of the beads obtained by simple drying and of a surface layer
10 of oxide or of hydroxide of the metal M are thus obtained.

In a fourth embodiment, the beads separated from the reaction medium by filtration are subjected to
15 calcination at a temperature of between 400°C and 800°C. Porous inorganic beads devoid of organic compounds, composed of a crosslinked inorganic matrix and the hydroxide of the cation of the salt which was used as crosslinking agent for the alginate, are thus
20 obtained. This embodiment is particularly appropriate when pore-forming organic agents were introduced into the reaction medium before the gelling of the alginate.

The process provided makes it possible to obtain graded
25 beads at a high rate. The size of the beads depends only on the size of the initial drop poured into the polyvalent salt solution. Another advantage lies in the fact that the preparation stages proper for the beads are carried out in an aqueous medium, which reduces the
30 risks of pollution related to the use of organic solvents. In addition, the beads obtained are biocompatible and can be prepared with components in accordance with regulations relating to foodstuffs and cosmetics.

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The present invention is illustrated in more detail by the following examples, to which, however, it is not limited.

Example 1

1 g of sodium alginate was dissolved in 50 ml of distilled water, and 6 g of sodium silicate $\text{Na}_2\text{Si}_3\text{O}_7$ were added dropwise to this solution with magnetic stirring. The aqueous solution obtained, referred to as "mother solution", is a viscous yellow solution which exhibits a pH in the region of 9.

An FeCl_3 solution (0.5M) was prepared by adding 4 g of FeCl_3 to 50 ml of distilled water, the pH of which was adjusted to a value between 0.6 and 0.8 by addition of an appropriate amount of hydrochloric acid. The mother solution was poured dropwise into said FeCl_3 solution using a syringe comprising a needle having an outlet diameter of 0.6 mm. On contact with the FeCl_3 solution, the drops of mother solution gelled and beads were formed. The reaction medium was left stirring using a magnetic stirrer for 14 h.

The beads were subsequently separated from the reaction medium by filtration, were rinsed with water and were poured into a 0.1M NaF solution prepared beforehand by addition of 0.2 g of NaF to 50 ml of distilled water. As the F^- ion is a catalyst for the condensation of silica, it makes possible rapid crosslinking of the sodium silicate. The reaction medium was kept stirred for 14 h and then the beads were separated by filtration.

A fraction of the beads thus recovered was retained in distilled water for the purpose of subsequent use.

A second fraction of the beads was dehydrated by maintaining in acetone for 2 hours and then drying in the air.

A third fraction of the beads was dehydrated by maintaining in acetone for 2 hours and then drying by lyophilization.

All the beads finally obtained exhibit a brown-red coloring resulting from the presence of the iron salt.

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Example 2

The procedure of example 1 was repeated, the 0.5M FeCl_3 solution being replaced by a 0.5M AlCl_3 solution, everything otherwise being equal. The beads obtained have a white coloring.

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Example 3

1 g of sodium alginate was dissolved in 50 ml of distilled water, and an aqueous suspension comprising 1.5 g of boehmite in 25 ml of distilled water was added dropwise to this solution with magnetic stirring. The aqueous solution obtained, referred to as "mother solution", is a viscous yellow solution which exhibits a pH in the region of 9.

20 An FeCl_3 solution (0.5M) was prepared by adding 4 g of FeCl_3 to 50 ml of distilled water, the pH of which was adjusted to a value between 0.6 and 0.8 by addition of an appropriate amount of hydrochloric acid. The mother solution was poured dropwise into said FeCl_3 solution using a syringe comprising a needle having an outlet diameter of 0.6 mm. On contact with the FeCl_3 solution, the drops of mother solution gelled and beads were formed. The reaction medium was left stirring using a magnetic stirrer for 14 h, the pH being maintained at 1 by addition of a hydrochloric acid solution (M).

The beads were subsequently separated from the reaction medium by filtration.

35 A fraction of the beads thus recovered was retained in distilled water for the purpose of subsequent use.

A second fraction of the beads was dehydrated by maintaining in acetone for 2 hours and then drying in

the air.

A third fraction of the beads was dehydrated by
maintaining in acetone for 2 hours and then drying by
5 lyophilization.

All the beads finally obtained exhibit a brown-red
coloring resulting from the presence of the iron salt.

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Example 4

1 g of sodium alginate was dissolved in 50 ml of
distilled water, and 6 g of sodium silicate $\text{Na}_2\text{Si}_3\text{O}_7$
were added dropwise to this solution with magnetic
stirring. The aqueous solution obtained, referred to as
15 "mother solution", is a viscous yellow solution which
exhibits a pH in the region of 9. 0.1 g of an inorganic
pigment with a pearlescent effect based on mica and on
titanium, in accordance with legislation relating to
cosmetic products, was added to this mother solution.

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An AlCl_3 solution (0.5M) was prepared by adding 3.3 g
of AlCl_3 to 50 ml of distilled water, the pH of which
was adjusted to a value between 0.6 and 0.8 by addition
of an appropriate amount of hydrochloric acid. The
25 mother solution comprising the pearlescent agent was
poured dropwise into said AlCl_3 solution using a
syringe comprising a needle having an outlet diameter
of 0.6 mm. On contact with the AlCl_3 solution, the
drops of mother solution gelled and beads were formed.
30 The reaction medium was left stirring using a magnetic
stirrer for 14 h.

The beads were subsequently separated from the reaction
medium by filtration, were rinsed with water and were
35 stored in distilled water.

Example 5

The procedure of example 4 was repeated but while
adding to the mother solution, in addition to the

pearlescent agent, an inorganic filler composed of 1.3 g of kaolin.

5 The beads obtained at the end of the stage of gelling the alginate exhibit a milky-pink coloring. The presence of the kaolin limits the shrinkage when the beads are dried in the air.

Example 6

10 1 g of sodium alginate was dissolved in 50 ml of distilled water, and an aqueous suspension comprising 1.5 g of boehmite in 25 ml of distilled water was added dropwise to this solution with magnetic stirring in order to prepare a mother suspension.

15 A colored aqueous solution was prepared separately by adding 3.3 g of AlCl_3 and 0.2 g of an organic orange pigment in accordance with legislation with regard to products for food and cosmetic use to 50 ml of
20 distilled water, the pH being adjusted to a value of between 0.6 and 0.8. The mother suspension was poured dropwise into said AlCl_3 solution using a syringe comprising a needle having an outlet diameter of 0.6 mm. On contact with the AlCl_3 solution, the drops
25 of mother suspension gelled and orange-colored beads in which the boehmite is crosslinked were formed.

The beads were separated by filtration, rinsed several times with water, to remove the acid residues, and then
30 stored in distilled water.

Example 7

0.74 g of a surface-active agent $\text{CH}_3(\text{CH}_2)_{14}(\text{CH}_2\text{CH}_2\text{O})_{12}\text{H}$ [sold under the name Tergitol 15S12 by Union Carbide]
35 was dissolved in 49 ml of deionized water. 2 ml of N hydrochloric acid were added and the solution was maintained at a temperature of less than 2°C . 5.9 g of sodium silicate ($\text{Na}_2\text{Si}_3\text{O}_7$) were subsequently added dropwise, which brought the pH to 9. At the same time,

1 g of sodium alginate was dissolved in 50 ml of deionized water and then this solution was added to the alginate solution to obtain a solution A.

A 0.1M nickel(II) chloride solution was also prepared
5 by adding 5 ml of an M aqueous nickel(II) chloride solution to 50 ml of deionized water.

The solution A was subsequently poured dropwise into the 0.1M nickel chloride solution and the formation of
10 beads by gelling of the alginate on contact with the nickel(II) chloride was observed. The reaction medium comprising the gelled beads was subsequently maintained at ambient temperature with magnetic stirring for 12 h.

15 The beads obtained were subsequently filtered off and rinsed with water and then they were poured into a 0.1M aqueous NaF solution obtained by dissolving 0.4 g of NaF in 100 ml of deionized water. The suspension was maintained at ambient temperature with magnetic
20 stirring for 24 hours. Subsequently, the beads were recovered by filtration and rinsed with water, and were stored in water.

The beads obtained can be used as solid catalyst
25 support.